EFFECTS OF CONTROLLED STORAGE ATMOSPHERES ON THE QUALITY, PROCESSING, AND GERMINATION OF PEANUTS

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EFFECTS OF CONTROLLED STORAGE ATMOSPHERES ON THE QUALITY, PROCESSING, AND GERMINATION OF PEANUTS

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ABSTRACT

Inshell and shelled runner peanuts were stored 6 and 12 months at 40° and 80° F in atmospheres of nitrogen, carbon dioxide, or air to determine if atmospheres containing less than 2 percent oxygen (to prevent insect infestation) would affect the quality, processing, and germination of stored peanuts. Atmosphere had no consistent effect on the germination of inshell peanuts. All shelled samples were essentially nonviable after 6 months. Storage temperature affected quality more than atmosphere, and, at 40° F after 12 months, peanuts stored in carbon dioxide or nitrogen had developed less browning of skins, staleness, or rancidity than those stored in air. Shelled peanuts varied less in processing, and, after 6 months, had more "cured" flavor as salted nuts or peanut butter. However, after 12 months, inshell peanuts were more stable for preparation of peanut products or for further storage.

INTRODUCTION

The increases in food production and in the storage of foods such as peanuts for long periods of time have increased the importance of the prevention of insect contamination and of prevention of damage to stored commodities. If the damage and contamination could be prevented by nonchemical means, the possible hazard of harmful chemical residues would be eliminated. The use of low-oxygen atmospheres is one of the more promising nonchemical control measures. When a viable commodity is sealed in an airtight container, the respiration of the commodity and of any insects present decreases the oxygen concentration and increases the carbon dioxide concentration. This alteration of atmospheric gases continues until there is not enough oxygen left to support insect life (*9*).[5]

Oxley and Wickenden (*7*) found that all insects in grain were killed when the oxygen concentration decreased to about 2 percent. Press and Harein (*8*), while observing 1-gallon jars of inshell and shelled peanuts into which 100 adult red flour beetles had been placed before sealing the jars in air, noted complete killing by cold alone at 40° F and by heat at 100° F before respiration had caused significant changes in atmospheric composition. Depletion of oxygen by respiration at 80° F killed all of the insects by the time residual oxygen had fallen below 1 percent, but slower reaction rates at 60° F allowed some insect damage (as well as deposits of viable eggs) over a period of more than 3 months.

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[5] Italic numbers in parentheses refer to items in "Literature Cited" at the end of this publication.

Peanuts are commonly stored in upright structures in the United States. It may not be practical to seal many of these structures so that they would be airtight, but it may be economically feasible to produce low-oxygen atmospheres by purging them with nitrogen or carbon dioxide. However, before any stored-product insect control method can be adopted, the effects of that method on the commodity and on the storage environment must be determined.

Eselgroth (*3, 4*) estimated threefold to sixfold extensions of storage life at temperatures up to 95° F by replacing air with carbon dioxide or nitrogen in the storage of some 30 types of processed foods, including various peanut products. In unprocessed foods, however, damage from anaerobic enzyme reactions has been reported for very low concentrations of oxygen, particularly in the presence of moderately high levels of storage moisture. Milner et al. (*6*) found that prevention of this type of damage required the addition of 1 percent oxygen to nitrogen used to flush stored wheat, and Acker (*1*) cited numerous reports of anaerobic damage from product-or residual-mold enzymes in grains and oilseeds stored in atmospheres containing less than 1 percent oxygen.

This paper covers studies designed to determine the relative effects of periodic (weekly) flushing with nitrogen, carbon dioxide, and air on the storage quality and germination of inshell and shelled raw peanuts.

MATERIALS AND METHODS

Runner peanuts from the 1964 crop were used in all tests. Quality tests of the peanuts before exposure to the various atmospheres showed them to be good, typical examples of peanuts suitable for use in experiments. No insects were included in this study, since their presence would have invalidated any processing or sensory tests.

ATMOSPHERIC GAS EXPOSURES

Thirty-six 1-gal glass bottles were filled with inshell peanuts (2.5 lb per bottle) and the same number and size with shelled peanuts (5.0 lb per bottle). Each bottle was sealed with a standard mason jar lid fitted with a rubber septum and two soldered sections of copper tubing. One section (introduction tube) extended to the bottom of the bottle, and the other section (exit tube) extended 1 inch below the lid. The outside of each lid was covered with tape and wax to insure as tight a seal as possible. Twelve bottles each of the inshell and shelled peanuts were flushed with commercial-grade nitrogen, 12 with commercial-grade carbon dioxide, and the remaining 12 with air. Both the nitrogen and carbon dioxide were at least 99.97 percent pure. The flushing continued until only the introduced gas could be detected by gas chromatography. One-half of each group of bottles was stored in a refrigerator maintained at 40° F and the other half at 80° F. During storage, the bottles were flushed weekly with the appropriate gases to maintain the desired atmospheres. Gas samples were removed immediately before each weekly purging and analyzed for nitrogen, carbon dioxide, and oxygen concentrations by a model 25V Fisher-Gulf partitioner.

TESTS FOR GERMINATION, MICROFLORA, MOISTURE AND SUGAR CONTENTS, AND QUALITY

Initially, and after 6 and 12 months of storage, samples of the raw peanuts were taken and tested for germination, microflora, moisture content, and quality. (Quality tests were also made after the peanuts had been processed.) Sugar content was determined after 12 months of storage.

Germination of peanuts from each sample was determined by rolling 25 fungicide-treated seeds in a paper towel. These rolls were stored in a germinator at 86° F for 8 hours and at 68° F for the next 16 hours. A light was on in some of the germinators during the 8-hour period.

The techniques and results of the microflora tests in this study were previously described by Jackson and Press (*5*).

Inshell peanuts were hand-shelled, and raw kernels of both inshell and shelled lots were tested for moisture content. Moisture contents of raw peanuts were determined as losses of total volatiles in heating 5 g of peanuts (of the size retained on a 14-mesh screen) for 5 hours at 203° F with pressure at 20 mmHg.

Reducing sugars and sucrose were determined with AOAC procedures and final Lane-Eynon titration (*2*).

The raw kernels of both inshell and shelled peanuts were tested for skin color. Skin color of intact kernels was recorded in tristimulus values —*L* or lightness (45° reflectance), *a* or red com-

ponent, and b or yellow component. Using a Hunter color and color difference meter set against a white standard, L= 89.3, a=—0.9, and b=—0.9.

The raw kernels of inshell and shelled peanuts were tested for freedom from various defects. Freedom from defects was scored as percentages of whole, sound kernels, baldface or slip-skin kernels, split kernels, edible pegs (kernels passing a ¼- by ¾-inch slotted screen), moldy kernels, and other damaged or inedible kernels.

PROCESSING

In initial and 6-month tests, enough peanuts to yield one 8-oz salted sample from inshell peanuts and two 8-oz samples from shelled peanuts were heated for about 13 minutes in a range oven at a thermostat setting of 350° F to loosen the skins, which were then removed by hand. The blanched kernels were cooked 7.5±0.5 minutes in 12 lb of coconut oil at 310°±10° F, with a Wells Autofry (model F-48) automatic fryer. They were then salted, cooled, packaged, and stored 3 days at room temperature to equalize oil, moisture, and volatiles. Similar procedures were followed in the 12-month test, except that skins were loosened by heating 10 minutes in a General Electric rotisserie oven (model R-20), at a thermostat setting of 400° F.

For each of the initial samples and for shelled peanuts after storage, peanut samples large enough to yield 2.0 to 2.3 lb of dry-roasted kernels were heated 34.5±0.5 minutes in the same rotisserie oven at 400° F. Because of shortages of stored inshell peanuts, 6- and 12-month inshell samples averaged only 12 oz of kernels after dry roasting, which reduced heating time to 16.7± 1.2 minutes. After roasting, skins and hearts were removed by handsplitting and screening.

The effects of processing on salted peanuts were determined as percentage losses or gains of weight from heating, blanching, and cooking and from "additional inedibles," or kernels that appeared good before removal of skins but which exhibited damaged areas or excessive browning after blanching or cooking.

For dry-roasted peanuts, the processing changes determined were percentage losses of weight resulting from heating, blanching, and removal of hearts, and from additional inedibles, as described above.

Peanut butter was prepared before and after storage from 2-lb samples of shelled peanuts only. After dry roasting, blanching, and degerminating, the peanuts were double-passed through a Morehouse mill (model MMS3), with a stone clearance of 0.001 inch. The only additive was 1 percent fine-crystal (30-mesh) salt, which was fed in with the peanuts on the first pass. Milling temperature was adjusted to 165°±5° F at the delivery chute.

RANCIDITY DETERMINATIONS

Rancidity values were determined for salted and dry-roasted peanuts that had been held at room temperature for 2 weeks after processing and for raw peanuts held under the same conditions immediately after storage. Oil was extracted from finely chopped peanuts with chloroform. The extract was adjusted to contain the standard sample quantities, 5.0±0.5 g of oil per 25 ml. Peroxide values were determined by adding 30 ml of glacial acetic acid and a few crystals of potassium iodide and titrating the liberated iodine (after a 2-minute reaction time terminated by addition of 100 ml of water and 1 ml of 1 percent starch) with sodium thiosulfate. Free fatty acids were determined by adding 25 ml of ethyl alcohol containing 0.1 percent phenolphthalein at a pH of 8.3 and titrating with sodium hydroxide in alcohol. Sample weights were found by evaporating the chloroform from a third set of standard volumes of extract in tared beakers and weighing the residual oil. All three determinations were made in duplicate.

SENSORY AND STATISTICAL EVALUATIONS

Sensory quality scores were assigned for all raw and processed samples. Scores for appearance, color, aroma, texture, and flavor were based on a 10-point scale, from 10 (excellent) to 1 (poor). Two examiners assigned the initial scores for the two raw samples. All other raw samples and all processed samples were scored by a panel of 10 experienced judges.

Assuming that the jars of peanuts contained 100 percent nitrogen or carbon dioxide immediately after flushing (with 79 percent nitrogen and 20.9 percent oxygen in the air-flushed jars), average weekly gas concentrations were estimated as midpoints between these and the values found by chromatographic analyses at the end of each week. Deviations of weekly averages

TABLE 1.—*Atmospheric gases in jars of peanuts stored at 40° and 80° F and purged with gases weekly for 12 months*[1]

Peanut type, storage temperature, purging gas	Atmospheric gas in jars (percent)					
	Nitrogen		Carbon dioxide		Oxygen	
	Mean[2]	Std. dev.[3]	Mean[2]	Std. dev.[3]	Mean[2]	Std. dev.[3]
Inshell at 40° F:						
Nitrogen	97.3	2.3	0.0	0.0	2.7	2.3
Carbon dioxide	5.5	6.4	93.4	7.7	1.1	1.5
Air	79.2	.3	.1	.1	20.7	.3
Inshell at 80° F:						
Nitrogen	99.3	1.3	.0	.0	.7	1.3
Carbon dioxide	5.5	6.4	93.5	7.9	1.0	1.5
Air	79.1	.7	[4]2.0	[4]1.8	[4]18.9	[4]1.3
Shelled at 40° F:						
Nitrogen	97.4	2.4	.0	.0	2.6	2.4
Carbon dioxide	8.7	6.2	89.4	7.9	1.9	1.8
Air	79.2	.3	.1	.1	20.7	.3
Shelled at 80° F:						
Nitrogen	98.0	2.5	.0	.0	2.0	2.5
Carbon dioxide	7.1	6.5	91.6	8.0	1.3	1.6
Air	79.4	.3	.1	.2	20.5	.3

[1] Data from Stored-Product Insects Laboratory, ARS, USDA, Savannah, Ga.
[2] Means of gas concentrations in 3 jars at the beginning and end of each week for 52 weeks.
[3] Pooled standard deviations of weekly concentrations from 12-month means.
[4] Some type of respiration apparently occurred in these peanuts.

from the respective 6-month sets of averages for three jars were then used to estimate the pooled standard deviations of weekly concentrations as given in table 1.

No variance data were available for the mean germination values in table 2. The significance of differences among means for all other data was estimated by standard procedures for analysis of variance and multiple-range testing at the 5-percent level of probability.

RESULTS AND DISCUSSION

ATMOSPHERIC GAS CONCENTRATIONS

The averages of the weekly percentages of nitrogen, carbon dioxide, and oxygen in the jars during the 12-month exposure period are given in table 1. Varying amounts of air leakage into the jars were clearly indicated by the oxygen found in all of the nitrogen and carbon dioxide atmospheres and in the nitrogen in the jars containing carbon dioxide. If relatively uniform rates of leakage are assumed during the weekly intervals between purging and sampling of the gases, maximum concentrations for the resulting oxygen and nitrogen may be estimated at about twice the tabular values. Such estimates would indicate weekly increases to above 5 percent oxygen in the nitrogen atmospheres of inshell and shelled peanuts at 40° F and to about 4 percent in shelled peanuts in carbon dioxide at 40° F and nitrogen at 80° F.

Of the 48 jars containing inert-gas atmospheres, the high oxygen values actually resulted from excessive leakage of only 6 jars during the first 6-month period and 3 jars during the second. The mean oxygen concentration in these jars was estimated at 3.8±1.4 percent, with mean weekly periods of 25±10 hours at less than 1 percent oxygen and 118±21 hours at more than 2 percent. Seven of the nine jars were at 40° F (at which insects do not develop), but damage might have resulted in two jars of shelled peanuts in nitrogen at 80° F had they acquired viable eggs before packing. The other 39 jars averaged 1.18±0.48 percent oxygen, with weekly means of 85±40 hours below 1 percent and only 31±31 hours above 2 percent; thus, insect control probably would have been adequate, even with initial exposure to insects or eggs.

No reactions of respiratory or other carbon-

LE 2.—*Percentage of germination in peanuts before and after storage in high concentrations of nitrogen, carbon dioxide, or air for 6 and 12 months*[1]

Peanut type, ge temperature, purging gas	Germination before storage	Germination after— 6 months	12 months
ell at 40° F:			
Nitrogen	82	74	83
Carbon dioxide	82	72	72
Air	91	77	75
ell at 80° F:			
Nitrogen	86	81	70
Carbon dioxide	85	83	78
Air	76	83	68
ed at 40° F:			
Nitrogen	81	1	4
Carbon dioxide	88	1	3
Air	80	1	2
ed at 80° F:			
Nitrogen	85	1	0
Carbon dioxide	84	0	0
Air	84	0	0

ests by E. E. Winstead, State seed analyst, Atlanta, anuts from Stored-Product Insects Laboratory.

ide-producing agents were indicated in any he nitrogen atmospheres nor in any of the ars, except those containing inshell peanuts)° F. In the latter, weekly accumulations of on dioxide averaged 2 percent during the ; 6 months and 5 percent during the second, corresponding depletions of oxygen. Slight es of very short mold mycelia on the shells me of these peanuts indicated that the car- dioxide production probably resulted from peanut and mold respiration in the air jars 0° F.

me depletion or selective absorption of the gen from air leakage was also suggested in f the carbon dioxide atmospheres. Weekly dual oxygen in these atmospheres averaged ±0.33 percent lower than that expected from corresponding nitrogen contents, the deficit g about 0.15 percent higher at 80° F than at F and higher at 12 months than at 6. Assum- that similar depletions took place in the ogen atmospheres without production of car- dioxide, this pattern indicated that the eases resulted from oxidative reactions with or other peanut components rather than ugh the action of respiratory enzymes. Thus, e observed changes in skin color and some erate decreases in sucrose each suggested the possibility of reducing or anaerobic deterioration reactions resulting from long periods at very low concentrations of oxygen, no direct evidence of such reactions was observed in the residual gases of the nitrogen or carbon dioxide atmospheres.

GERMINATION TESTS

The influence of storage atmospheres on germination was slight and relatively insignificant in comparison with those of time, temperature, and shelling (table 2). Initial germination averaged 84±7.5 percent for inshell peanuts and 84±4 percent for shelled peanuts. Average germination for inshell peanuts was 76±5 percent from 40° F storage after 6 and 12 months and 72±5 percent from 80° F storage after 12 months, with no consistent pattern of difference attributable to atmosphere. Shelled peanuts averaged only 2±2 percent viability at 40° F and were essentially nonviable within 6 months at 80° F. This phenomenon of loss of viability after shelling (except after very careful hand shelling, which does not bruise the kernels) is well known, but the almost complete loss of viability within 6 months at 40° F was perhaps a bit surprising. When atmosphere alone is considered, these data indicate no apparent disadvantage in storing peanuts in nitrogen or carbon dioxide.

MICROFLORA TESTS

Results of the microflora tests (*5*) indicated that fungi on the surfaces of pods of the unshelled peanuts were not significantly affected by the storage gases. However, a significant decrease in numbers was noted after 6 and 12 months at 80° F as compared with those periods at 40° F. Fungi, including *Aspergillus flavus*, cultured from stored shelled peanuts were also not significantly affected by the storage gases, but a significant increase in numbers was noted after 12 months at 40° F.

MOISTURE CONTENT

The moisture content of the shelled peanuts (as received) was 6.04±0.08 percent and of the inshell peanuts was 7.54±0.10 percent (table 3). Identical treatments during storage equalized the moisture contents to about 6.65 percent for air and 6.40 percent for gases at 40° F and to 6.00 percent for air and 5.75 percent for gases at 80° F.

TABLE 3.—*Percentages of moisture and sugar in peanuts after storage in nitrogen, carbon dioxide, or air for 12 months*[1]

Peanut type, storage temperature, purging gas	Moisture (wet basis)	Sugar (dry basis)		
		Reducing sugars	Sucrose	Total
Inshell at 40° F:[2]				
Nitrogen	6.34	0.026	4.27	4.30
Carbon dioxide	6.51	.068	4.72	4.79
Air	6.72	.068	4.32	4.39
Inshell at 80° F:[2]				
Nitrogen	5.80	.036	3.86	3.90
Carbon dioxide	5.81	.095	3.65	3.75
Air	6.07	.057	4.01	4.07
Shelled at 40° F:[3]				
Nitrogen	6.45	.057	4.88	4.94
Carbon dioxide	6.23	.025	4.44	4.47
Air	6.59	.073	4.34	4.41
Shelled at 80° F:[3]				
Nitrogen	5.68	.051	3.69	3.74
Carbon dioxide	5.64	.066	4.27	4.33
Air	5.97	.071	4.24	4.31
SD at 5% level[4]	.09	.060	1.08	1.05

[1] Determinations made in samples held 1 week in sealed plastic bags at ambient temperatures after removal from storage.
[2] Initial moisture content (air) was 7.54 percent.
[3] Initial moisture content (air) was 6.04 percent.
[4] SD, significant difference.

SUGAR CONTENT

No significant amounts of reducing sugars were found in the peanuts after 12 months, but lower levels of sucrose in all nitrogen samples at 80° F and in the inshell samples in carbon dioxide at 80° F suggested that some hydrolytic or other deteriorative reaction had occurred in the inert-gas atmospheres (table 3). The slight decrease of sucrose in inshell air samples at 80° F could have been the result of continued respiratory activity in these peanuts, but no carbon dioxide production (such as that cited by Acker, (*1*), in several reports of anaerobic respiration) was observed in the nitrogen atmospheres nor was there any apparent relationship to fungal discolorations. Therefore, it seems possible that the decrease of sucrose could have resulted from incomplete and low-rate reactions, probably inhibited by relatively low moisture and periodic leakage of small amounts of oxygen into the jars. Whatever the reactions, they did not result in significant reductions of product quality, though in this respect they could have had a borderline effect.

QUALITY TESTS

Initial Hunter color values for intact peanut skins and color changes resulting from storage are given in table 4. As seen from the decreases in L values, storage at 80° F resulted in significant skin darkening in all of the shelled kernels and in the inshell kernels in air. There was relatively little change in lightness of the shelled kernels in any of the atmospheres at 40° F or in inshell kernels in nitrogen or carbon dioxide at 80° F. Inshell peanuts at 40° F became lighter, indicating the absence of oxidative skin reactions and possibly some tendency toward reducing reactions after 6 or 12 months in carbon dioxide or 12 months in nitrogen.

The general increase in red color (largely responsible for corresponding increases in red/yellow ratio) was typical for aging peanut skins. Inshell samples at 40° F and inshell samples at 80° F in nitrogen and carbon dioxide increased slightly in yellowness, resulting in a somewhat lighter orange appearance, as noted above. The shelled samples at 40° F had relatively less change in red color, tending to darken slightly

TABLE 4.—*Changes in skin color of peanuts stored in nitrogen, carbon dioxide, or air for 6 and 12 months*[1]

Peanut type, storage temperature, purging gas	Hunter color values (NBS units)[2]					
	L (lightness)		*a* (red)		*a/b* (red/yellow)	
	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo
Inshell at 40° F:[3]						
Nitrogen	38.7	39.7	19.7	20.2	1.69	1.64
Carbon dioxide	40.4	39.8	20.9	20.5	1.76	1.67
Air	37.9	38.8	21.0	19.6	1.80	1.63
Inshell at 80° F:[3]						
Nitrogen	37.9	39.2	21.8	20.8	1.91	1.80
Carbon dioxide	38.8	38.5	22.2	22.0	1.71	1.87
Air	33.7	32.1	20.9	20.5	1.80	1.90
Shelled at 40° F:[4]						
Nitrogen	34.6	34.7	20.6	19.7	1.78	1.65
Carbon dioxide	34.9	35.0	20.7	19.3	1.78	1.67
Air	34.1	34.9	19.7	19.0	1.73	1.59
Shelled at 80° F:[4]						
Nitrogen	33.7	31.5	21.3	21.8	1.70	1.93
Carbon dioxide	33.1	32.3	20.6	21.3	1.70	1.89
Air	31.6	30.2	20.4	21.2	1.73	1.94
SD at 5% level[5]	1.3	1.4	1.0	1.0	0.10	0.09

[1] These and subsequent data from University of Georgia, Georgia Station, Experiment, on peanuts from Stored-Product Insects Laboratory.

[2] NBS, unit of color difference. (Judd, D.B. 1939. Specification of color tolerances at the National Bureau of Standards. Am. J. Psychol. 52: 418.)

[3] Initial color values (air)—$L=38.2$, $a=16.7$, and $a/b=1.47$.

[4] Initial color values (air)—$L=34.9$, $a=18.6$, and $a/b=1.5$.

[5] SD, significant difference. Significant differences at 5% level of probability between storage periods—$L=1.1$, $a=0.9$, and $a/b=0.10$.

during early storage but fading toward original color as storage continued. The inshell kernels in air at 80° F and all shelled peanuts at 80° F increased more or less progressively in redness while decreasing in both lightness and yellowness, characteristic of typical, moderate browning of skins.

Although temperature appeared to have more influence than storage atmospheres on skin color, the sensory judges noted the fading or oranging effect of inert gases on inshell samples at 40° F. From an original point score of 9.2, these samples averaged 7.5 at 6 months and 6.6 at 12 months. Dulling and darkening in air made relatively more difference in the other groups. From the original point score of 9.2 for the inshell samples and 8.7 for the shelled samples, final scores averaged 7.35 for gas samples and 6.30 for air samples in both the inshell group at 80° F and the shelled group at 40° F and 6.45 for gas samples and 5.20 for air samples in the shelled group at 80° F.

Defects in kernels consisted mostly of baldface (slipped skins) and split kernels, particularly in shelled peanuts, in which defects increased progressively in storage at 80° F. Similar increases also occurred in shelled peanuts in nitrogen and carbon dioxide at 40° F. Inshell peanuts and air-stored shelled peanuts at 40° F reached approximate equilibria within 6 months. Storage atmospheres had no apparent influence on percentages of baldfaces, but splits averaged about 1 percent higher in air.

Final storage values for handling damage to inshell kernels, which were hand shelled, averaged 0.43 percent for baldface, 2.95 percent for splits in inert gases, and 3.95 percent for splits in air. Final averages for machine-shelled kernels (with 2.6 percent for baldface and 3.8 percent for splits before storage) were 7.4 percent for balds for all samples except those in carbon dioxide and air at 40° F, which averaged 4.6 percent, and 4.75 percent for splits for all samples except those in nitrogen and air at 80° F, which averaged 5.95 percent. Thus, despite slightly lower moisture equilibria from flushing with the

purified gases, there were no consistent differences in handling damage between gas and air-storage samples.

Kernel mold did not become a problem, but there were slight traces on a few inshell kernels from samples at 40° F and on 0.2 to 0.6 percent of the shelled kernels from both temperatures. Since there was no apparent association of mold with storage atmospheres, and it did not appear particularly "dried," it is possible that it developed after the samples were removed from storage and packaged for holding until examination. Other damage, most of which was discoloration from rot fungi, was confined largely to small kernels or pegs from inshell peanuts. Edible pegs and damaged kernels were graded down to 0.4 percent in shelled peanuts before storage, and discoloration averaged 0.35 percent at 6 months and 0.28 percent at 12 months. A different pattern was exhibited in the inshell kernels, which increased in discoloration from 1.5 percent before storage to 3.6 percent after 6 months but dropped to 0.8 percent during the second 6-month period. The reduction of moisture in the inshell peanuts and their fading in cool storage or inert atmospheres probably accounted for the decrease, since the shelled kernels in air at 80° F were the only samples that did not decrease, averaging 0.4, 0.5, and 0.8 percent at the three examinations. The discoloration of 5.3 percent at 6 months and 2.8 percent at 12 months in the inshell kernels stored in air at 80° F was probably associated, at least in part, with the respiratory reactions that continued in these samples throughout storage.

The shells of the inshell peanuts changed very little during storage. The only variation in "ease of hand shelling" was a slight toughening of shells in samples held 12 months in nitrogen, particularly in those from storage at 40° F. Color variations and mold growth on shells occurred in only one environment, 80° F in air. Shells from these samples varied somewhat in external and internal color, possibly because of oxidation of some tanninlike component, but the condition did not become pronounced. Traces of dry mold on some of the inner surfaces of these shells suggested a slight molding of partly cracked shells during the early weeks of storage, when the inshell peanuts still contained excess moisture. However, the depletion of oxygen in the inshell air samples at 80° F throughout storage could have been associated with molding, since it was not possible to estimate how long the mycelial growth had continued or whether mold enzymes had remained active after growth ceased. Lack of oxygen apparently prevented similar growth of mold on the shells in nitrogen and carbon dioxide atmospheres, and lack of sufficient moisture apparently suppressed molding of shelled kernels stored in air.

EFFECTS OF PROCESSING

The moisture contents of the peanuts (7.5 percent for inshell and 6.0 percent for shelled) tended to equalize during storage at about 6 percent. As a result, processing losses for the inshell samples decreased but remained fairly uniform for both inshell and shelled peanuts at 6 and 12 months. Average losses were 3.0 percent in heating for salting, 5.1 percent in dry roasting, and 2.7 percent in blanching for both products. Loss of weight in processing varied somewhat with storage temperature. At 40° F, peanuts retained slightly more moisture and averaged around 0.3 percent more weight loss when heated. No consistent relationship was apparent between weight loss and storage atmospheres, but there was considerable variation among storage groups.

Additional discards after processing consisted largely of kernels from which skins could not be entirely removed after heating or roasting. After 12 months of storage this condition was more pronounced in the heated kernels intended for salting than in the fully roasted kernels, particularly in inshell peanuts stored in carbon dioxide and in shelled kernels stored in air. These two groups of samples averaged 7.2 percent for discards, as compared with 4.0 percent for other 12-month salted samples and 1.3 percent for all other salted and dry-roasted samples. There was little average difference between sample groups stored at 40° F and those stored at 80° F or in total discards from inshell and shelled samples, but greater numbers of kernels with brown spotting (resembling fungal damage after heating) were found in the shelled groups stored at 80° F. General uneven browning occurred more frequently in the inshell samples stored at 40° F.

RANCIDITY

Peroxide (or initial-stage-oxidation) values and free-fatty-acid (or hydrolysis) values for oils extracted from the raw and processed peanuts are given in table 5.

All values for the raw peanuts, particularly ıose for peroxides, were undoubtedly influenced / holding the samples for approximately 2 eeks in air at room temperature between re-oval from storage and extraction of the oil. he results, however, clearly indicated some re-rdation of both peroxidation and hydrolysis om storage of inshell and shelled peanuts at)° F and from storage of inshell peanuts as mpared to shelled peanuts. Free fatty acids veraged about 0.1 percent lower at 40° F than 80° F in the inshell samples at 6 months, and e inshell samples averaged less than 0.3 per-nt after 12 months at both temperatures. ıelled peanuts at 12 months were in the range which hydrolysis is usually associated with ecreases in flavor quality. Peroxides developed ore slowly in the inshell peanuts in inert gases, ırticularly at 40° F. Since the gradual accumu-tion of peroxides usually indicates an inhibi-ın of secondary oxidation reactions, the inshell anuts at 40° F were judged to be the only group itable for storage beyond 12 months.

Since peroxides are both volatile and quite active at temperatures used in oil cooking or asting, the values shown in table 5 were assumed to have developed during the 2-week holding period after processing. The inshell peanuts from the nitrogen atmosphere at 40° F were relatively stable as salted peanuts after both periods of storage. The other samples were apparently more resistant to secondary oxidation reactions at 6 months, when the peroxides accumulated, than at 12 months, when the secondary reactions apparently utilized them as fast as they formed. This pattern is normal for low-moisture, heat-processed foods, and the inhibiting effects of inshell storage at 40° F are seen in the 6-month data in table 5 which also indicates that the period of inhibition had passed before the 12-month period ended. With moisture reduced to relatively low and uniform levels by cooking, there was no significant association of free fatty acids with storage temperatures.

The oxidation pattern of dry-roasted peanuts appeared somewhat different from that of the salted peanuts, possibly because of the absence of the coconut-oil coating that the salted peanuts acquired in cooking or because of the absence of salt, which may act as a prooxidant. Peroxidation in the inshell samples at 40° F remained fairly uniform, again with greater stability in nitrogen.

ABLE 5.—*Rancidity values for oil from peanuts after storage in nitrogen, carbon dioxide, or air for 6 and 12 months*

Peanut type, storage temperature, purging gas	Peroxide values (meq/kg)						Free fatty acids (pct as oleic acid)					
	Raw		Salted[1]		Dry-roasted[1]		Raw		Salted[1]		Dry-roasted[1]	
	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo
shell at 40° F:												
N_2	0.09	0.28	0.00	0.13	0.18	0.12	0.16	0.15	0.16	0.16	0.16	0.16
CO_2	.00	.26	.58	.19	.34	.39	.16	.19	.15	.18	.17	.16
Air	.10	.31	1.10	.00	.34	.36	.16	.17	.16	.16	.17	.14
shell at 80° F:												
N_2	.07	.04	.19	.16	.35	.89	.23	.32	.24	.23	.21	.26
CO_2	.07	.15	.13	.00	.14	.38	.24	.28	.21	.24	.22	.27
Air	.31	.28	.19	.00	.30	.16	.25	.28	.22	.24	.24	.28
elled at 40° F:												
N_2	.15	.31	.62	.11	.26	.34	.38	.35	.19	.23	.21	.23
CO_2	.12	.12	.96	.14	.00	.33	.27	.34	.21	.22	.22	.26
Air	.15	.27	.77	.00	.00	.30	.33	.33	.19	.22	.22	.27
ıelled at 80° F:												
N_2	.16	:02	.20	.12	.00	.48	.63	.69	.31	.42	.42	.50
CO_2	.21	.29	.19	.04	.00	.37	.58	.60	.34	.45	.40	.49
Air	.07	.16	.57	.10	.00	.28	.51	.76	.35	.41	.41	.47
SD at 5% level[2]	.07	.06	.09	.10	.10	.10	.021	.021	.014	.015	.023	.025

[1] Raw peanuts stored as shown, then processed and held 2 weeks at 73° F before oil was extracted.

[2] SD, significant difference. Significant differences at 5% level of probability between storage periods for peroxide values—raw = 0.06, salted = 0.09, and dry-roasted = 0.09; for fatty acids—raw = 0.021, salted = 0.014, and dry-roasted = 0.023.

Results were variable for inshell peanuts at 80° F, but all of the shelled peanuts (except those from nitrogen at 40° F) had completed the initial postshelling cycle of peroxidation during the first storage period, and, judging from reductions in sensory quality, had assumed a secondary stage of oxidation as dry-roasted peanuts by the end of the second period.

Hydrolysis or free-fatty-acid values were similar to those for salted peanuts, with considerably less time effect but with somewhat greater temperature differences than shelled samples.

SENSORY EVALUATIONS

Taste ratings for texture of the raw, salted, and dry-roasted peanuts averaged near 8.0 points and were apparently not associated with any of the various storage factors. Ratings for appearance and color varied with fading of skins in inert gases at 40° F or darkening of skins in air at 80° F and with irregular browning or spotting of processed peanuts, as previously discussed. Mean ratings for aroma and flavor of the raw, salted, and dry-roasted peanuts are given in table 6.

There was little difference in scores for aroma and flavor of raw kernels from storage of inshell samples at 40° F, the mean rating being 7.13± 0.24 points. Since there was no significant variation associated with storage atmospheres, there were different reasons for the reductions from the initial rating of 9.5 points. The peanuts from nitrogen were described as slightly musty, those from carbon dioxide, slightly sour, and those from air, slightly stale. Flatness or lack of cured flavor was also noted, and the inshell samples from storage at 80° F for 6 months averaged 1 point higher for having more typical flavor than those from storage at 40° F for 6 months. However, the staling effects of the higher temperature reduced the scores of the inshell samples at 80° F by the end of the second period.

Both temperature and atmospheric effects were noted in the shelled peanuts. In nitrogen samples from storage at 40° F, the shelled peanuts averaged 1.5 points higher than the inshell peanuts at 6 months, and all other shelled pea-

TABLE 6.—*Aroma and flavor ratings for peanuts after storage in nitrogen, carbon dioxide, or air for 6 and 12 months*[1]

Peanut type, storage temperature, purging gas	Peanut samples					
	Raw		Salted[2]		Dry-roasted[2]	
	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo
Inshell at 40° F:[3]						
Nitrogen	7.0	7.35	6.05	6.95	6.90	6.35
Carbon dioxide	7.0	6.95	6.65	6.55	6.65	6.15
Air	7.5	6.95	6.90	6.35	7.20	6.10
Inshell at 80° F:[3]						
Nitrogen	8.0	7.30	6.80	6.15	6.65	7.05
Carbon dioxide	8.0	7.25	6.85	6.15	6.90	6.15
Air	8.5	6.95	7.30	5.65	6.65	5.60
Shelled at 40° F:						
Nitrogen	8.5	7.70	6.90	7.15	6.85	5.90
Carbon dioxide	7.5	7.50	7.35	6.70	6.90	5.40
Air	7.0	7.55	7.20	7.40	6.65	6.15
Shelled at 80° F:[4]						
Nitrogen	6.0	7.05	7.20	6.55	6.65	5.05
Carbon dioxide	5.5	7.15	7.00	6.70	6.45	5.55
Air	4.5	6.70	7.05	5.75	6.25	4.35
SD at 5% level[5]	1.01	1.01	1.01	1.06	0.96	1.08

[1] Mean of 20 ratings on scale from 10 (excellent) to 1 (poor).
[2] Raw peanuts stored as shown, then processed and held 2 weeks at 73° F.
[3] Initial sensory-quality scores (air)—raw=9.5, salted=6.79, and dry-roasted=7.22.
[4] Initial sensory-quality scores (air)—raw=9.0, salted=7.13, and dry-roasted=6.95.
[5] SD, significant difference. Significant differences at 5% level of probability between storage periods—raw=0.86, salted=0.91, and dry-roasted=0.96.

nuts at both 6 and 12 months were also rated slightly higher as having more typical, cured flavor. Shelled samples scored lower than inshell samples at 80° F after the first 6 months; the reductions were attributed to aromatic off odors and flavors from inert-gas storage and to slight rancidity in the peanuts from air. These off odors and flavors were apparently concentrated in the skins and outer surfaces of kernels (probably a result of shelling damage), as scores increased back to near the score level of the inshell samples after continued flushing of the atmospheres during the second half-year period.

As is well known in commercial practice, storage odors generated by kernel reactions or those associated with customary bagging or packaging materials tend to dissipate with handling and subsequent heat processing of peanuts after removal from storage. Thus, there was almost no carryover of the slightly musty, sour, or aromatic odors noted in the samples from the glass jars. Reductions in the aroma and flavor scores for the salted peanuts were caused by lack of full flavor, staleness, or variations in uniformity of processing.

Mean scores for salted peanuts averaged about the same at both examination periods for samples from storage at 40° F, with shelled-storage ratings about 0.55 of a point higher than inshell ratings for having more cured peanut flavor (table 6). Inshell samples averaged higher at 80° F than at 40° F, and shelled samples from both temperatures rated about the same at 6 months. Staling and uneven processing, particularly in the inshell samples for air storage, reduced all scores for samples at 80° F after 12 months.

The effects of the atmospheres varied with each of the other storage factors. The air sample rated highest of the inshell samples at 40° F after 6 months and the nitrogen sample lowest, with complete reversal at 12 months. Similar reversals between the air sample and each of the inert-gas samples of inshell peanuts from storage at 80° F was probably influenced by the continued respiratory reactions in the air-sample peanuts, since processed color was quite uneven after the second period. Somewhat less pronounced unevenness was also noted in the inert-gas inshell samples and was possibly associated with low-oxygen storage, which apparently resulted in depletions of sucrose. Differences were generally less pronounced and more variable in the shelled samples at 40° F, with the air sample at 12 months receiving the highest score for a processed sample. The shelled peanuts at 80° F were fairly uniform at 6 months, averaging 7.08±0.11 points, but the inert-gas samples averaged 0.5 of a point lower than that at 12 months. The air sample was 1.3 points lower at 12 months.

The overall quality pattern of the dry-roasted peanuts differed from that of the salted peanuts in the effects of shelling, storage temperature, and time, all of which were considerably more uniform in the dry-roasted samples. Unlike the salted peanuts, aroma and flavor scores for dry-roasted peanuts averaged progressively lower in shelled samples than in inshell samples and lower in samples from storage at 80° F than in those from storage at 40° F. Also, 11 of 12 dry-roasted lots averaged 0.94 of a point lower at 12 months than at 6 months, whereas only 9 of 12 salted samples averaged 0.73 of a point lower at 12 months. This pattern agrees with the usual observation that dry-roasted nuts show a more pronounced response to storage influences than do salted nuts, which develop more covering flavor from oil cooking.

The relationship of storage atmospheres to the quality of dry-roasted peanuts was somewhat less variable, but again the mean effects were more definite than with salted peanuts. Average aroma-flavor point scores for dry-roasted peanuts from carbon dioxide and air atmospheres were 6.03 and 6.68 (in favor of air) for the scores of inshell samples stored at 40° F for 6 months averaged with the scores of shelled samples stored at 40° F for 12 months, and point scores ranged to 5.55 and 4.35 (in favor of carbon dioxide) for shelled peanuts stored at 80° F for 12 months. Mean scores were 6.27 points for carbon dioxide and 6.12 points for air. Nitrogen samples averaged slightly higher (6.43 points), eliminating the mean advantage of air storage at 40° F and increasing the maximum advantage of nitrogen storage to 1.45 points for inshell peanuts at 80° F.

Peanut butter, prepared only from shelled samples, scored higher than the dry-roasted peanuts in all quality categories, since uneven processing had less influence after the kernels were ground. The only significant storage effect at 6 months was a general reduction in the scores for butter made from peanuts stored in nitrogen

at 40° F, which did not roast as uniformly as the other samples and which made butter described as dull in color and flat in aroma and flavor. This sample was better at 12 months, with the gas samples averaging 7.3 points and the air sample 6.8 points. The samples at 80° F reacted more definitely to storage time, with an overall average of 7.03±0.25 points at 6 months, but 6.3 points for the gas samples and 5.1 points for air samples at 12 months. With the exception of these differences, however, there was no regular pattern of differences in scores for any atmosphere.

CONCLUSIONS

The results of the studies showed that storing peanuts in atmospheres of nitrogen or carbon dioxide containing 1 to 2 percent oxygen can be substituted for chemical fumigation and air storage without significant decreases in germinating ability, stability for processing, or product quality.

There were no consistent differences in the germinating ability of inshell peanuts after storage in air or in the inert gases. Shelled peanuts, although expected to decrease in viability as a result of shelling injury, were not expected to become almost completely nonviable, as they did within 6 months in all atmospheres. However, none of the observed differences would support an assumption of any disadvantage from holding shelled-seed stocks in nitrogen or carbon dioxide for shorter periods of storage, with the provision that oxygen levels do not fall below 1 percent. Decreases of sucrose and uneven color resulting from the processing of peanuts held at 80° F in nitrogen or carbon dioxide (with oxygen below the 1-percent level for several days each week) suggested that both seed stocks and commercial edibles may be damaged by anaerobic respiration reactions if oxygen concentrations become low enough to permit the establishment of reducing conditions.

Differences in processing and sensory quality, as well as in chemical stability of the oil in the peanuts, were more pronounced between storage at 40° and 80° F than between air and carbon dioxide or nitrogen storage. Thus, although certain advantages were indicated for the low-oxygen atmospheres, these did not of the undesirable effects of the high ture. Aroma and color were better in r (and general quality higher in dry-r nuts) from carbon dioxide and nitro stored at 40° F at the first examinat "cured peanut" flavor of the salted p peanut butter from air storage at 80° preferred. After 12 months, the air- nuts were definitely browner in ski produced staler or more nearly ranci particularly those that had been stor

There was apparently no great ac inshell storage as compared to shel for the periods used. The raw and sa peanuts were flatter in flavor and v in appearance, color, and processing istics. Rancidity values and genera by the judges indicated, however, tha peanuts, after 12 months storage, stable for preparation of peanut pro further storage.

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